EMISSIONS AND AIR QUALITY RELATIONSHIPS FOR ATMOSPHERIC TRACE METALS

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1. INTRODUCTION

Atmospheric particulate matter samples taken in urban and rural locations can be analyzed routinely for more than forty trace elements. With the increasing use of automated X-ray fluorescence and neutron activation analyses (Dzubay, 1977; Cooper, 1973), the cost of trace metals determination in airborne particulate samples has been greatly reduced. As a result, large volumes of data are being acquired that contain considerable chemical resolution, including concentration data on toxic trace elements like lead, arsenic, cadmium and nickel.

While air quality data that define toxic metals pollutant loading in the atmosphere are becoming available, the emission sources responsible for the release of these materials often are not obvious. Trace metals emissions arise from more than 60 distinctly different source types in a large urban area. There are, for example, autos burning leaded fuel, electric arc steel furnaces, Kraft recovery boilers, and secondary lead smelters. The U.S. Environmental Protection Agency (1977) emission factor manual (AP-42) presents a fairly comprehensive list of the source types that might be present, and there are many of them. This proliferation of sources and the fact that trace metals often are only a minor fraction of the mass emissions from each source obscures the relative importance of the contributors to atmospheric metals levels.

The purpose of this chapter is to illustrate methods available for quantifying the sources that contribute trace metals emissions to the atmosphere. Receptor-oriented air quality models will be described that can identify the contribution of individual emission source types to the aerosol mass loading observed at community air monitoring sites. It will be shown how trace metals emission inventories can be used to improve receptor model reliability. A comprehensive emission inventory procedure will be developed for each of the individual trace metals released to the atmosphere. The consistency of these inventories will be tested based on comparison of the relative abundance of trace metals estimated from emissions data versus that measured in the atmosphere. Examples will be given based on data available for Los Angeles, California and for Houston, Texas.

2. SOURCE APPORTIONMENT BY CHEMICAL MASS BALANCE METHODS

Trace metals emissions undergo atmospheric dilution and transport, resulting in the pollutant concentrations observed at community air monitoring sites. Knowledge of the relative importance of each of many emission source types to air quality at receptor air monitoring stations is a prerequisite to the design of efficient pollutant abatement strategies. Mathematical air quality models can be constructed based on observed meteorological data that will track the contributions from many emission sources as they undergo atmospheric chemical reaction and pollutant transport. These fluid mechanical dispersion models are elegant, but the data requirements in practical applications can become so large that engineers are detered from using

them to solve complex multiple source urban air quality problems (see Cass and McRae, 1981b).

In the case of particulate emissions, an alternative to the use of fluid mechanical transport models is available. It is possible to attack the source contribution identification problem in reverse order, proceeding from measured air quality at a receptor site backward to the responsible emission sources. The unique metals content of the emissions from each source type is viewed as a tracer for the presence of material from that source in an ambient aerosol sample (Hidy and Friedlander, 1970; Miller et al., 1972; Friedlander, 1973; Kowalczyk et al., 1977). A chemical mass balance then is constructed on the concentration c_i of each element $i = 1,2,\ldots,n$ in the ambient sample based on a linear combination of the chemical element profiles of the major emission sources present:

$$c_i = \sum_j f_{ij}\, a_{ij}\, s_j \qquad (1)$$

where s_j is the mass concentration of material from sources $j = 1,2,\ldots,m$ observed at the receptor site, a_{ij} is the fraction of chemical species i in the particulate emissions from source j, and f_{ij} is the coefficient of fractionation, representing any modification to the source emission profiles (the a_{ij}'s) due to gravitational settling or other atmospheric processes that occur between the source and the receptor point. Fractionation often is neglected.

Equation (1) defines a series of expressions, each one of which constitutes a mass balance on a single chemical element in

an aerosol sample. Given the chemical composition of the ambient sample and the source emission profiles, Equation (1) may be solved for the source contributions, s_j. In cases where the number of chemical elements exceeds the number of source types, one linear combination that fits the ambient sample can be found by least squares regression:

$$\underset{\sim}{s} = [A^T W A]^{-1} A^T W \underset{\sim}{c} \qquad (2)$$

where $\underset{\sim}{s}$ is a vector of estimated source contributions to the ambient sample, $\underset{\sim}{c}$ is a vector of the concentrations of species i = 1,2,...,n measured at the monitoring site, A is the matrix $f_{ij}\ a_{ij}$ appearing in Equation (1), and W is a diagonal matrix of weighting factors. The weighting factors are selected to reflect the accuracy with which the concentration of a particular chemical species is measured. A common choice for these weighting factors is $1/\sigma_i^2$, where σ_i is the standard deviation of a single determination of the concentration of species i in an ambient sample (Kowalczyk et al., 1977).

3. EMISSION INVENTORY ASSISTED RECEPTOR MODELS

In the early stages of receptor model development, investigators had chemically resolved source signatures available for only 5 to 10 source types and did not face two important problems: (1) a number of source profiles exceeding the number of elements measured, or (2) <u>extreme</u> multicollinearity, with many industrial sources indistinguishable from one another on the basis of chemical

composition. As the number of source profiles increases, these two problems can become quite serious.

If a chemical element balance application is to be useful under such circumstances, some method must be used to reduce the number of source signatures applied to the mass balance equations to well below the number of actual types of sources in an air basin. There are perhaps four ways to accomplish this reduction: intuition, "interactive" chemical mass balance approaches, factor analysis, and emission inventory assisted chemical mass balance approaches. The intuitive approach generally results in a priori selection of only those profiles that belong to sources that are obviously important, such as the automobile. In the interactive chemical mass balance method (Heisler, 1982), one utilizes all available source profiles in the initial mass balance calculations, discarding sources with predicted negative source contributions one at a time beginning with those having the largest relative uncertainty in the value of s_j. Then, once all predicted source contributions are positive, the analyst continues to remove sources one at a time, again beginning with those having the largest relative uncertainty in the value of s_j, until the source combination yielding the best fit to the ambient data is found. Factor analysis often is used to estimate the minimum number of important source types present by synthesizing source profiles that in combination will reproduce the chemical composition of a series of samples (Henry, 1977; Hopke et al., 1980; Alpert and Hopke, 1980; Hopke, 1981). Each of the above methods has serious drawbacks: intuitive selection of the

important source profiles is arbitrary, the interactive approach depends on the judgement and skill of the analyst when deciding which sources to delete, and factor analysis can result in a collection of synthetic source profiles that look nothing like the chemical composition of the effluent from any real emission sources.

The fourth alternative for reducing the dimension of the chemical mass balance problem is to use an emission inventory assisted approach (Cass and McRae, 1981a; 1983). Emission inventory data are used to systematically assess the ability of a limited number of source types to complete a mass balance on selected chemical species measured in ambient samples. Extraneous sources are eliminated from consideration in two ways. First, sources shown to constitute a negligible fraction of the mass emissions of all easily traced elements are eliminated from the source matrix. If the air sampling site of interest is not in the immediate vicinity of such a source, then the source will not be detected, even if present. Secondly, with the assistance of mass emission inventory data, source profiles for a variety of activities that are linked together physically, so that their emissions occur in known proportions with the same spatial distribution, can be combined into a single emissions-weighted average profile. For example, all highway traffic emissions from catalyst-equipped autos and light trucks, leaded gasoline fueled autos and trucks, diesel vehicles, tire dust and brake dust can be combined into a single profile that often will be easily identified by its lead content. Likewise, the many dissimilar sources at a steel mill,

petroleum refinery, or entire industrial complex might be combined into a single profile for the facility as a whole. In some cases, an equivalent to these composite profiles could be obtained experimentally by atmospheric sampling, e.g., in a highway tunnel. But the composite based on an emission-weighted average of several single source profiles has the advantage that the mass associated with the composite, once identified at a receptor site, can be separated easily into the impact of each single source within the group. This is important for control strategy evaluation purposes if each source in the composite group is to be controlled by different techniques and to a different degree. The emission inventory assisted approach can be used to resolve receptor modeling problems that resist solution by other methods because it brings additional data to bear on the problem, not just a different mathematical data reduction procedure.

Obviously, for an emissions inventory assisted chemical element balance analysis to work, the emissions inventory and ambient monitoring data must be accurate. Further, there is no guarantee that any particular air basin will necessarily have a population of sources that can be reduced to a manageable number by this method. Therefore, the first step in this approach is to run consistency checks on the available data and to determine if the problem can be formulated so that a mass balance can be achieved on key chemical elements without the source matrix becoming degenerate. In some cities this series of checks will succeed, whereas in others it will fail. One procedure for making this determination is as follows.

4. TRACE METALS EMISSIONS

A comprehensive inventory of trace metals emissions is constructed for each mobile, stationary and fugitive source type in the air basin. An energy balance is constructed on the region's fuel supply. Fuel combustion data next are combined with information on the level of industrial process and fugitive source activity, and an inventory of total suspended particulate emissions to the atmosphere is computed by standard methods (Cass et al., 1982; U.S. Environmental Protection Agency, 1972; Taback et al., 1979). This inventory should be based, if possible, on source tests performed within the air basin of interest. If fuel switching is practiced on a seasonal basis, the inventory should be computed from fuel use during the time span of the ambient sampling program.

Next the particulate inventory is subdivided into fine and coarse particle fractions using data on the size distributions of the particulate matter emitted from the sources of interest. Then the size-resolved mass emissions inventory is converted into a separate inventory for each chemical compound or element of interest by multiplying the mass emissions rate from each source type by its fractional chemical composition within the particle size range of interest. An example of the size distribution of the chemical composition of the particulate emissions from a petroleum refinery fluid catalytic cracking unit is given in Table 1. Similar data on the size distribution of the chemical composition of the emissions from more than 60 types of important particulate pollutant sources have been

accumulated and cataloged in several useful reference works (Watson, 1979; Taback et al., 1979; Cass and McRae, 1981a).

An element-by-element emission inventory for fine particulate matter in the Los Angeles area can be used to illustrate the power of the size-resolved source fingerprint method for trace metals emissions estimation. The example chosen is based on Cass and McRae (1981a, 1983) and involves 70 separate pollutant source types and 39 source chemical composition profiles.

The geographic area studied is the South Coast Air Basin that surrounds Los Angeles, as shown in Figure 1. An energy budget within that region during the year 1976 first was constructed by the methods of Cass et al. (1978; 1982). This fuel burning survey was combined with industrial process and fugitive source emission data provided by Taback et al. (1979) and by Grisinger et al. (1981). An inventory of total particulate emissions then was constructed as shown in Table 2. Information on the size distribution and chemical composition of emissions from 39 different source types was used to divide the total particulate burden into inventories for each of 37 different chemical species within the fine particle size range (particle diameter, $d_p \leq 10$ μm). A complete description of this emission inventory procedure is given by Cass and McRae (1981a).

The Los Angeles fine particle trace element inventory is summarized in Table 3 and for some of the key elements studied in Figure 2 and Table 4. The crustal elements silicon, aluminium, iron

and calcium, are among the largest contributors to particulate air quality. They are emitted to the Los Angeles atmosphere principally in the form of fugitive dust. Primary aerosol carbon and primary sulfates also account for a significant fraction of the particulate emissions from combustion sources. Lead is the most abundant of the toxic trace metals, emitted principally from combustion of leaded gasoline. Nickel is emitted at the rate of about one half metric ton per day, largely from combustion of residual fuel oil. Other toxic trace elements like arsenic and cadmium are emitted at the rate of a few tens of kg daily. Fifty-eight percent of the mass of the Los Angeles fine particulate emissions can be accounted for by the elements listed in Table 3. Most of the remaining material consists of oxygen and hydrogen, with the metals often present as oxides.

5. CONFIRMATION TESTS

Next, a consistency check is performed on the emission inventory and ambient monitoring data. The total mass emission rates for fine particle iron, silicon, aluminium etc., are rank ordered. The relative abundance of each element in the fine particle emissions inventory is compared to the relative abundance of elements in long-term average ambient monitoring data at stations within the urban plume of the city. Results of such a comparison for elements traditionally monitored in the Los Angeles atmosphere are shown in Figure 3. With the exception of Cu and Co, the agreement between the relative abundance of elements in both emissions and air quality data is quite good. The mismatch for copper in that case is known to be due to contamination of the samples

by copper worn from the high-volume sampler motors (Radke et al., 1977), whereas the mismatch for cobalt is probably due to slight cobalt contamination of the source signature for natural gas combustion taken at a source that periodically burns fuel oil.

Consistency checks also can be performed on the ambient data separately to assure that the ambient data are of high quality. The ambient data can be reviewed to see if lead and bromine concentrations are highly correlated (both usually arise from the same source, leaded auto exhaust). Crustal elements can be checked for high cross-correlation.

6. SOURCE PROFILE SELECTION FOR RECEPTOR MODEL CALCULATIONS

The mass emission inventory for each chemical element or compound next is examined, as shown in Figure 2. Elements are sought that serve as nearly unique tracers for one or a very few sources. These are the elements for which a nearly complete mass balance can be constructed using only a few source profiles. In the Los Angeles example shown in Figure 2, soil-like crustal materials dominate Fe and Mn emissions, Pb is a nearly unique tracer for the automobile, and fuel oil dominates Ni emissions. In contrast, metals like Zn, Cd and Cr arise from small contributions from a large number of industrial and fugitive sources (see Table 4) that are grouped together in Figure 2. Zinc alone is emitted from more than forty different source types, and it is clear that a mass balance equation cannot be written successfully for zinc in Los Angeles unless an exceptionally large number of source profiles are

used in the data reduction process. Since the number of elements used in the solution of Equations (1) and (2) must equal or exceed the number of source profiles present, the inclusion of an accurate mass balance equation for an element like zinc would substantially increase the dimension of the source assignment problem.

On the basis of the emission inventory findings summarized in Figure 2, a near mass balance can be achieved on iron, manganese, nickel, vanadium and lead in Los Angeles that can probably identify the relative importance of crustal material (soil or road dust), fuel oil fly ash, and leaded highway vehicle exhaust. The emission inventory further can be used to help quantify additional source contributions by linking together sources that have the same spatial and temporal distribution of emissions as one of the readily traced sources given above. Leaded automobile exhaust can be tracked by our receptor model. Those emissions are accompanied by other roadway emissions including diesel engine exhaust, exhaust from automobiles burning unleaded fuel, tire wear and brake lining dust. A composite source profile for all highway emissions is constructed in Table 5 based on an emissions inventory weighted average of each of these source types. If that composite profile is used in the chemical mass balance equations in place of leaded auto exhaust profile, then five source types can be tracked simultaneously rather than just leaded auto exhaust alone.

7. RECEPTOR MODEL RESULTS

The emission inventory assisted chemical mass balance method has been applied to Los Angeles (Cass and McRae, 1981a, 1983). The source profiles for fuel oil fly ash, highway aerosol, crustal emissions, plus secondary sulfates and nitrates given in Table 6 were fit to the chemical elements for which a near mass balance could be assured: Pb, Fe, Mn, Ni, $SO_4^=$, and NO_3^- at South Coast Air Quality Management District (SCAQMD) monitoring sites and Pb, Fe, Mn, V, $SO_4^=$ and NO_3^- at National Air Surveillance Network (NASN) sites. As seen in Figure 4, the material balance clearly accounts for about 80% of the total suspended particulate matter (TSP) concentrations at most high volume sampler sites in that city, even if only a few chemical elements are available for use in the model.

8. IDENTIFICATION OF APPLICATIONS WHERE CHEMICAL MASS BALANCE MODELS MAY NOT PERFORM WELL

By contrast, the emission inventory assisted method applied to a city such as Houston, Texas, shows that not all urban areas can be modeled as readily as Los Angeles. The 1980 particulate emission inventory provided for the Houston area by the U.S. Environmental Protection Agency's National Emission Data System and by Environmental Research and Technology (Heisler et al., 1981) was associated with local soil dust composition data (Stevens, 1982) and with source profiles assembled by Taback et al. (1979), Watson (1979), and Cass and McRae (1981a). An element by element fine particle emission inventory was created by the methods described previously. In Figure 5, the

available emission inventory data for Houston are compared to the average of ambient fine particle concentration data obtained by Dzubay et al. (1982) during September 1980 at a monitoring site on the University of Houston campus. It is seen that emissions and air quality data do not match as closely as in Los Angeles but that the general trend from abundant to rare elements is evident. The Houston emission inventory may be incomplete or inaccurate. Atmospheric Ca, Si and Fe concentrations do not match the total inventory in relative abundance, nor do they closely match the composition of local soil dust. Manganese is present at a level consistent with stated road and soil dust emissions, but is low compared to the total emission inventory. Aluminium concentrations by X-ray fluorescence are close to their abundance in both soil and the total inventory. Bromide and Cl are depleted relative to the inventory, as expected if they are being displaced from the aerosol by reaction with acidic sulfates or nitric acid. Airborne sodium exceeds the abundance in the inventory, perhaps because sea salt is excluded as a fugitive source in the local emission inventory. Phosphorus and Ba are both elevated in the atmosphere and rare in source emissions. They probably could be used to identify their source(s) if locally obtained source profiles were available for all sources. A phosphate fertilizer plant is present in Houston but no corresponding source signature is available.

The information given in Figure 6 shows why receptor modeling problems in Houston will be tough to solve given available data. In contrast to Los Angeles, very few elements act as nearly unique tracers

for one or two sources. Lead sources other than leaded auto exhaust are evident. Bromine would be a good tracer for leaded gasoline use, but it is not conserved in the aerosol phase. Aluminium would be the best soil dust tracer, but crustal emissions still account for only 71% of the local aluminium emissions. There are an enormous number of industrial sources of the other conventionally crustal elements, such as Si, Ca, Fe and Mn. Most of the ambient vanadium data are below the detection limit, and the vanadium content of local soil dust is not known.

If one wishes to proceed with a chemical mass balance analysis of the Houston data set, the next step is to assemble composite emission profiles for the steel mill, pulp mill, petroleum refineries, etc., until enough sources are included to nearly complete a mass balance on the abundant easily detected elements. When this is done it is found that the ferroalloy furnaces, steel mill, pulp mill, and fluid catalytic cracking unit signatures are in many cases nearly linear combinations of one another. This renders the chemical mass balance problem nearly degenerate. The emissions inventory assisted chemical mass balance method thus indicates that the present data base for Houston is not a highly promising candidate for mass balance based receptor models. This situation might be improved by a better emission inventory and locally determined source profiles.

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FIGURE CAPTIONS

Figure 1. Location of Monitoring Sites Within the South Coast Air Basin

Figure 2. Summary of Fine Particle Trace Metals Emissions in the Los Angeles Area - 1976

Figure 3. Comparison of Emissions and Air Quality Data in the Los Angeles Area

Figure 4. Chemical Mass Balance Model Results in the Los Angeles Area - 1976

Figure 5. Comparison of Emissions and Air Quality Data in the Houston Area

Figure 6. Summary of Fine Particle Trace Metals Emissions in the Houston Area - 1980

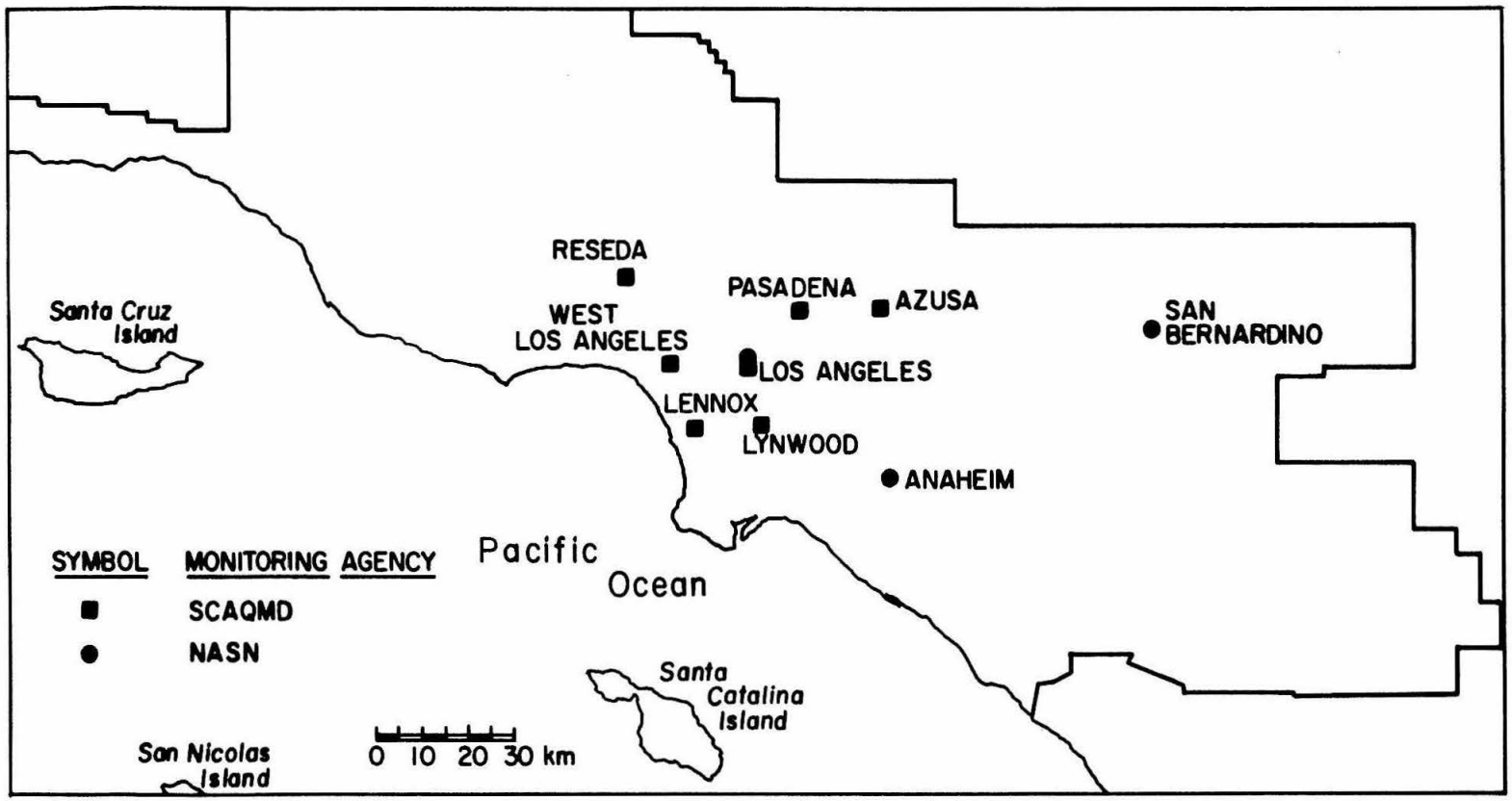

RESEDA
PASADENA
AZUSA
SAN BERNARDINO
Santa Cruz Island
WEST LOS ANGELES
LOS ANGELES
LENNOX
LYNWOOD
ANAHEIM
SYMBOL
MONITORING AGENCY
SCAQMD
NASN
Pacific Ocean
Santa Catalina Island
San Nicolas Island
0 10 20 30 km

FIGURE 1

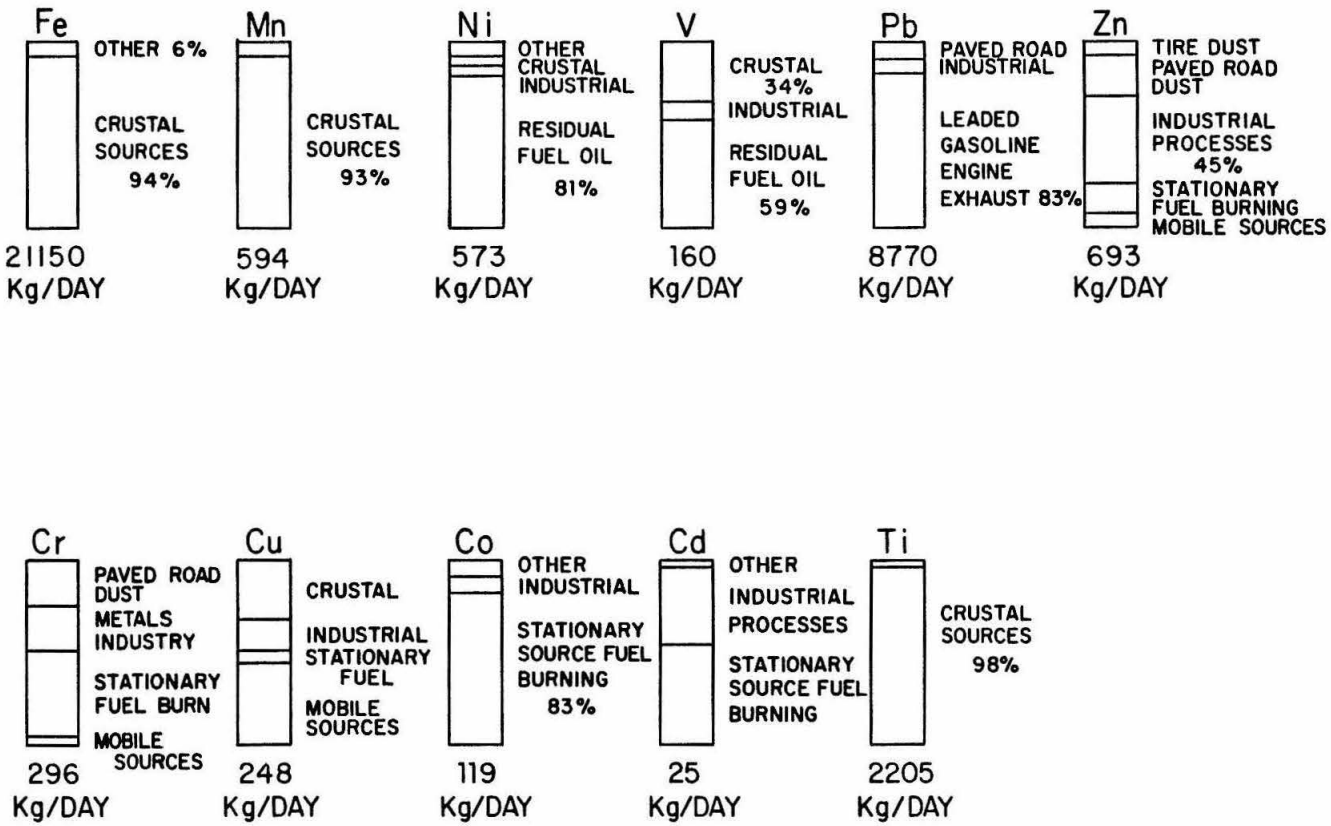

Fe
OTHER 6%
CRUSTAL SOURCES 94%
21150 Kg/DAY
Mn
CRUSTAL SOURCES 93%
594 Kg/DAY
Ni
OTHER CRUSTAL INDUSTRIAL
RESIDUAL FUEL OIL 81%
573 Kg/DAY
V
CRUSTAL 34%
INDUSTRIAL
RESIDUAL FUEL OIL 59%
160 Kg/DAY
Pb
PAVED ROAD INDUSTRIAL
LEADED GASOLINE ENGINE EXHAUST 83%
8770 Kg/DAY
Zn
TIRE DUST
PAVED ROAD DUST
INDUSTRIAL PROCESSES 45%
STATIONARY FUEL BURNING MOBILE SOURCES
693 Kg/DAY
Cr
PAVED ROAD DUST
METALS INDUSTRY
STATIONARY FUEL BURN
MOBILE SOURCES
296 Kg/DAY
Cu
CRUSTAL
INDUSTRIAL STATIONARY FUEL
MOBILE SOURCES
248 Kg/DAY
Co
OTHER INDUSTRIAL
STATIONARY SOURCE FUEL BURNING 83%
119 Kg/DAY
Cd
OTHER INDUSTRIAL PROCESSES
STATIONARY SOURCE FUEL BURNING
25 Kg/DAY
Ti
CRUSTAL SOURCES 98%
2205 Kg/DAY

FIGURE 2

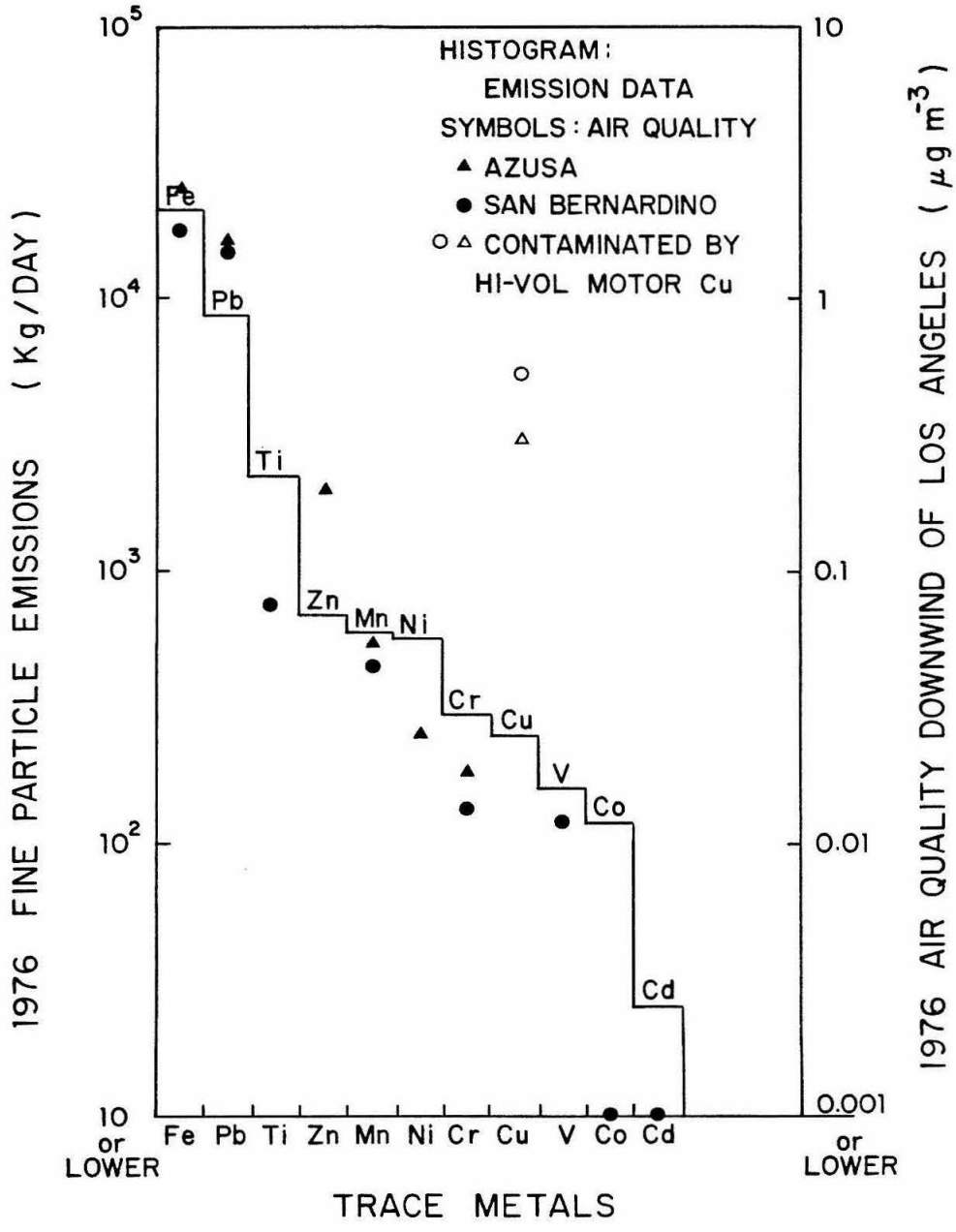
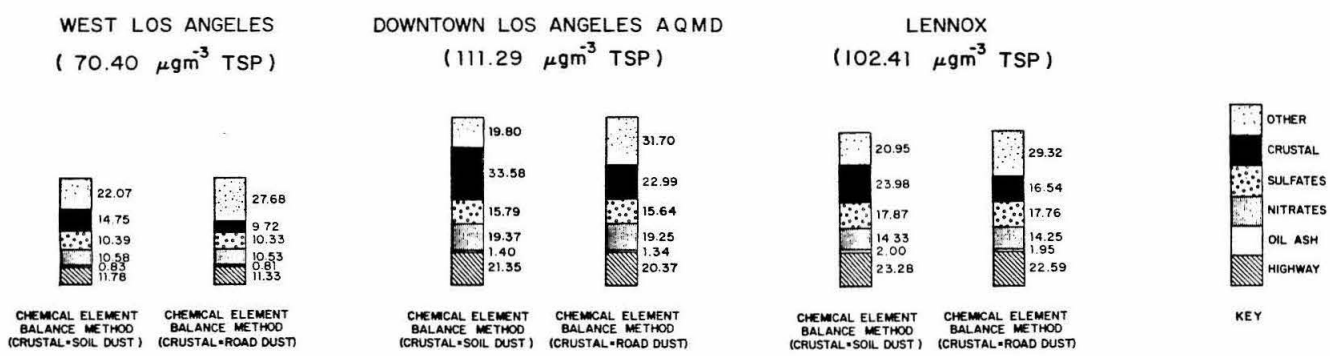
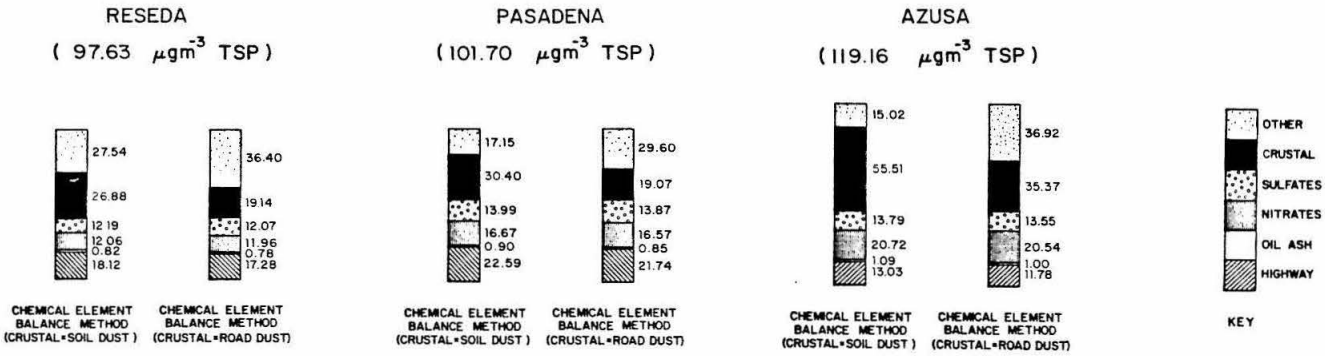

HISTOGRAM:
EMISSION DATA
SYMBOLS: AIR QUALITY
▲ AZUSA
● SAN BERNARDINO
○ △ CONTAMINATED BY
HI-VOL MOTOR Cu
1976 FINE PARTICLE EMISSIONS (Kg/DAY)
1976 AIR QUALITY DOWNWIND OF LOS ANGELES (μg m⁻³)
10⁵
10⁴
10³
10²
10
10
1
0.1
0.01
0.001
Fe
Pb
Ti
Zn
Mn
Ni
Cr
Cu
V
Co
Cd
10 or LOWER
or LOWER
TRACE METALS

FIGURE 3


WEST LOS ANGELES
(70.40 μgm-3 TSP)
22.07
14.75
10.39
10.58
0.83
11.78
27.68
9.72
10.33
10.53
0.81
11.33
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
DOWNTOWN LOS ANGELES AQMD
(111.29 μgm-3 TSP)
19.80
33.58
15.79
19.37
1.40
21.35
31.70
22.99
15.64
19.25
1.34
20.37
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
LENNOX
(102.41 μgm-3 TSP)
20.95
23.98
17.87
14.33
2.00
23.28
29.32
16.54
17.76
14.25
1.95
22.59
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
OTHER
CRUSTAL
SULFATES
NITRATES
OIL ASH
HIGHWAY
KEY


RESEDA
(97.63 μgm-3 TSP)
27.54
26.88
12.19
12.06
0.82
18.12
36.40
19.14
12.07
11.96
0.78
17.28
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
PASADENA
(101.70 μgm-3 TSP)
17.15
30.40
13.99
16.67
0.90
22.59
29.60
19.07
13.87
16.57
0.85
21.74
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
AZUSA
(119.16 μgm-3 TSP)
15.02
55.51
13.79
20.72
1.09
13.03
36.92
35.37
13.55
20.54
1.00
11.78
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
OTHER
CRUSTAL
SULFATES
NITRATES
OIL ASH
HIGHWAY
KEY

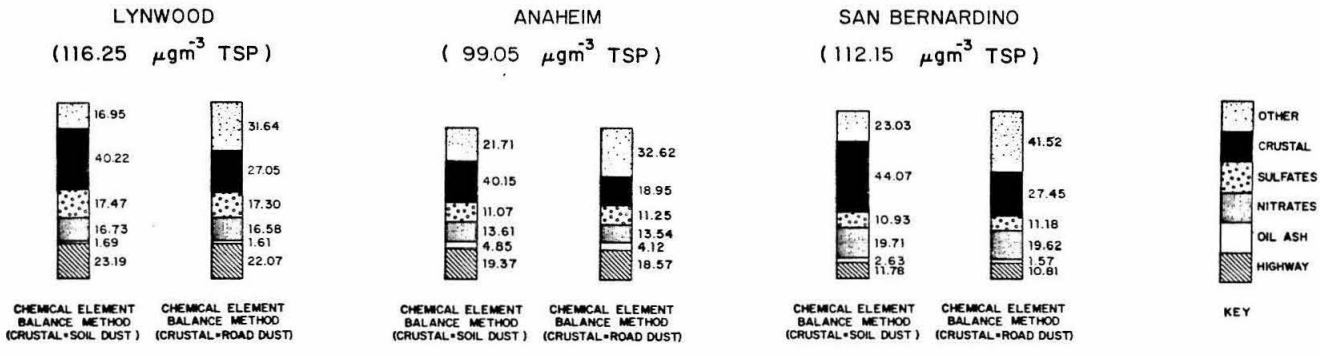

LYNWOOD
(116.25 μgm-3 TSP)
16.95
40.22
17.47
16.73
1.69
23.19
31.64
27.05
17.30
16.58
1.61
22.07
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
ANAHEIM
(99.05 μgm-3 TSP)
21.71
40.15
11.07
13.61
4.85
19.37
32.62
18.95
11.25
13.54
4.12
18.57
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
SAN BERNARDINO
(112.15 μgm-3 TSP)
23.03
44.07
10.93
19.71
2.63
11.78
41.52
27.45
11.18
19.62
1.57
10.81
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+SOIL DUST)
CHEMICAL ELEMENT BALANCE METHOD (CRUSTAL+ROAD DUST)
OTHER
CRUSTAL
SULFATES
NITRATES
OIL ASH
HIGHWAY
KEY

FIGURE 4

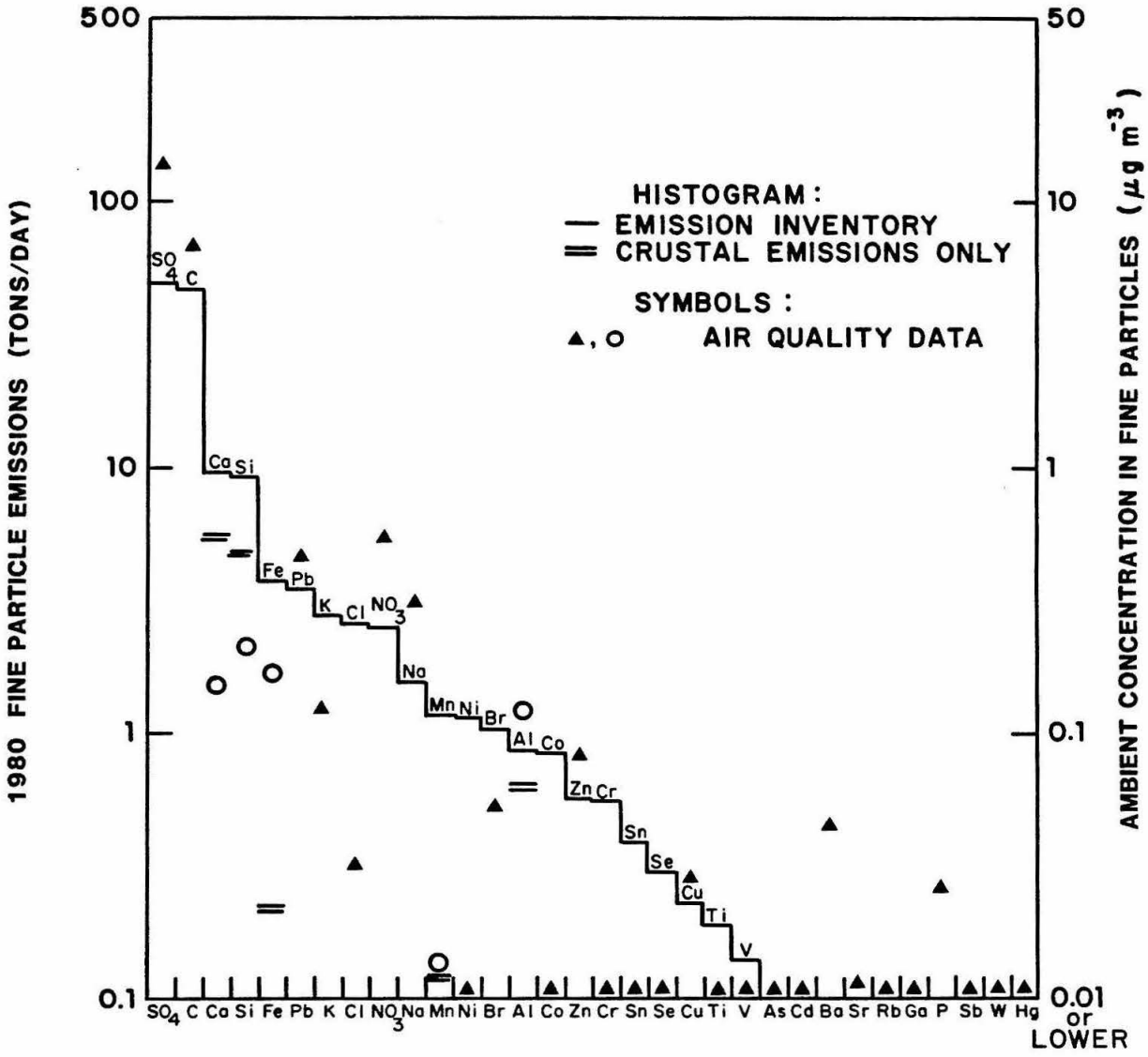

1980 FINE PARTICLE EMISSIONS (TONS/DAY)
AMBIENT CONCENTRATION IN FINE PARTICLES (μg m⁻³)
500
100
10
1
0.1
50
10
1
0.1
0.01 or LOWER
HISTOGRAM :
— EMISSION INVENTORY
═ CRUSTAL EMISSIONS ONLY
SYMBOLS :
▲, O AIR QUALITY DATA
SO4 C Ca Si Fe Pb K Cl NO3 Na Mn Ni Br Al Co Zn Cr Sn Se Cu Ti V
SO4 C Ca Si Fe Pb K Cl NO3 Na Mn Ni Br Al Co Zn Cr Sn Se Cu Ti V As Cd Ba Sr Rb Ga P Sb W Hg

FIGURE 5

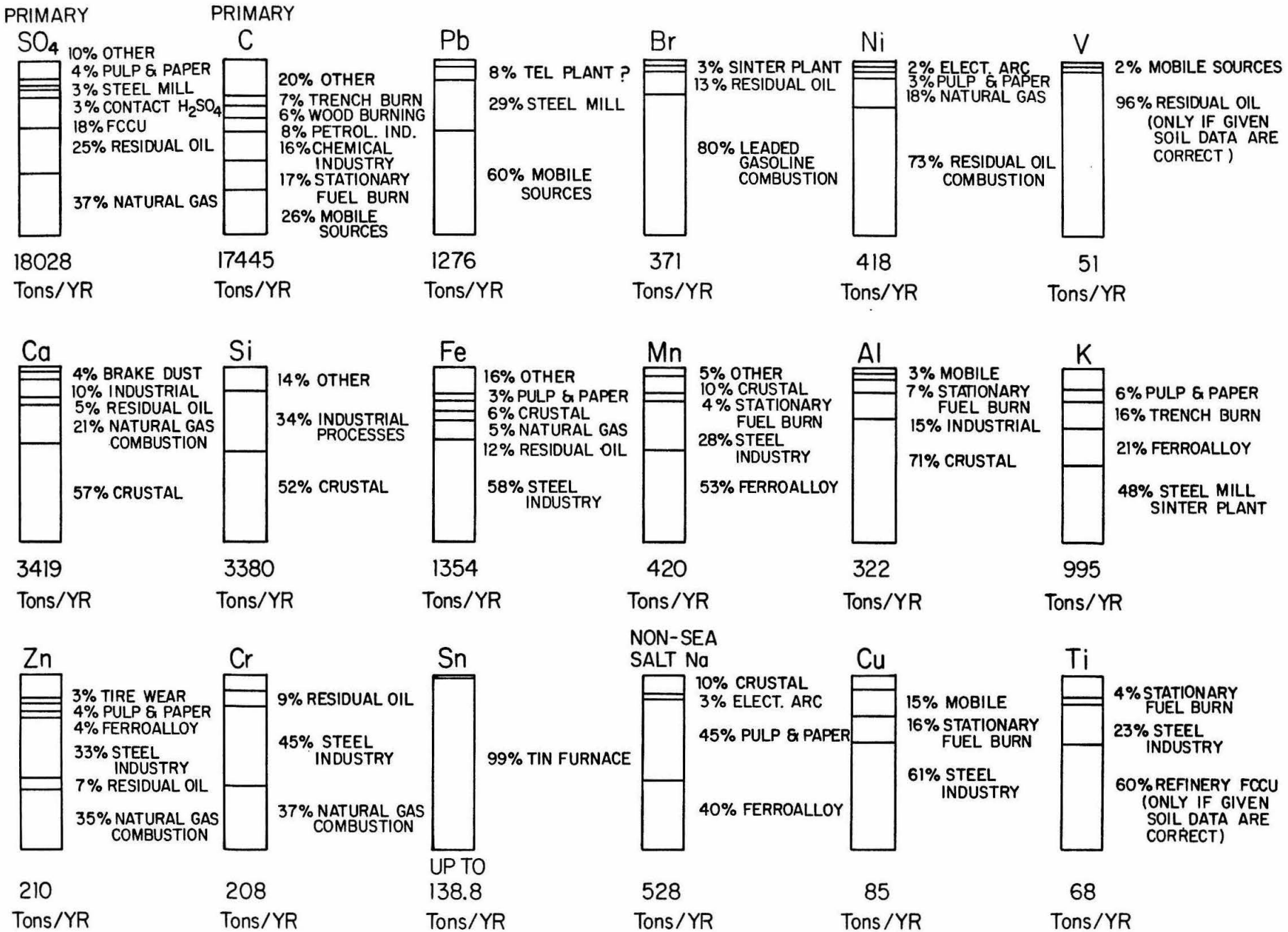

PRIMARY
SO4
10% OTHER
4% PULP & PAPER
3% STEEL MILL
3% CONTACT H2SO4
18% FCCU
25% RESIDUAL OIL
37% NATURAL GAS
18028
Tons/YR
PRIMARY
C
20% OTHER
7% TRENCH BURN
6% WOOD BURNING
8% PETROL. IND.
16% CHEMICAL INDUSTRY
17% STATIONARY FUEL BURN
26% MOBILE SOURCES
17445
Tons/YR
Pb
8% TEL PLANT ?
29% STEEL MILL
60% MOBILE SOURCES
1276
Tons/YR
Br
3% SINTER PLANT
13% RESIDUAL OIL
80% LEADED GASOLINE COMBUSTION
371
Tons/YR
Ni
2% ELECT. ARC
3% PULP & PAPER
18% NATURAL GAS
73% RESIDUAL OIL COMBUSTION
418
Tons/YR
V
2% MOBILE SOURCES
96% RESIDUAL OIL (ONLY IF GIVEN SOIL DATA ARE CORRECT)
51
Tons/YR
Ca
4% BRAKE DUST
10% INDUSTRIAL
5% RESIDUAL OIL
21% NATURAL GAS COMBUSTION
57% CRUSTAL
3419
Tons/YR
Si
14% OTHER
34% INDUSTRIAL PROCESSES
52% CRUSTAL
3380
Tons/YR
Fe
16% OTHER
3% PULP & PAPER
6% CRUSTAL
5% NATURAL GAS
12% RESIDUAL OIL
58% STEEL INDUSTRY
1354
Tons/YR
Mn
5% OTHER
10% CRUSTAL
4% STATIONARY FUEL BURN
28% STEEL INDUSTRY
53% FERROALLOY
420
Tons/YR
Al
3% MOBILE
7% STATIONARY FUEL BURN
15% INDUSTRIAL
71% CRUSTAL
322
Tons/YR
K
6% PULP & PAPER
16% TRENCH BURN
21% FERROALLOY
48% STEEL MILL SINTER PLANT
995
Tons/YR
Zn
3% TIRE WEAR
4% PULP & PAPER
4% FERROALLOY
33% STEEL INDUSTRY
7% RESIDUAL OIL
35% NATURAL GAS COMBUSTION
210
Tons/YR
Cr
9% RESIDUAL OIL
45% STEEL INDUSTRY
37% NATURAL GAS COMBUSTION
208
Tons/YR
Sn
99% TIN FURNACE
UP TO
138.8
Tons/YR
NON-SEA SALT Na
10% CRUSTAL
3% ELECT. ARC
45% PULP & PAPER
40% FERROALLOY
528
Tons/YR
Cu
15% MOBILE
16% STATIONARY FUEL BURN
61% STEEL INDUSTRY
85
Tons/YR
Ti
4% STATIONARY FUEL BURN
23% STEEL INDUSTRY
60% REFINERY FCCU (ONLY IF GIVEN SOIL DATA ARE CORRECT)
68
Tons/YR

FIGURE 6

TABLE 1

Source Profile

Petroleum - FCC Units/CO Boiler[a]

Size Range (Micron)	0-99	0-1	1-3	3-10	10-99	0-10
Weight Percent (%)	100.00	51.00	6.00	4.00	39.00	61.00
Species						
Arsenic	0.05[b]	0.05	0.05	0.05	0.05	0.05
Calcium	0.55[c]	0.55	0.55	0.55	0.55	0.55
Cesium	1.00	2.00	1.00	1.00	1.00	1.836
Gallium	0.05	0.05	0.05	0.05	0.00	0.05
Iron	0.55	1.00	1.00	0.500	0.55	0.967
Lanthanum	0.55	0.55	0.55	5.550	0.55	0.878
Lead	0.05	0.05	0.05	0.05	0.05	0.05
Molybdenum	0.05	0.05	0.05	0.05	0.05	0.05
Neodymium	0.55	0.55	0.55	0.55	0.55	0.55
Nickel	0.05	0.05	0.05	0.05	0.05	0.05
Praeseodymium	0.55	0.55	0.55	0.55	0.55	0.55
Silicon	10.00	0.05	20.00	20.00	20.00	3.320
Strontium	0.05	0.05	0.05	0.05	0.05	0.05
Titanium	0.55	0.55	0.55	0.55	0.55	0.55
Sulfates	30.00	50.00	6.00	7.00	7.00	42.852
Total Carbon	2.00	4.00	0.00	0.00	0.00	3.344
(Volatile Carbon)	1.500	3.00	0.00	0.00	0.00	2.508
Other	53.400	39.900	68.950	63.450	68.450	44.302
Totals	100.00	100.00	100.00	100.00	100.00	100.00

(a) **Basis: Taback et al. (1979)**

(b) Elements detected at concentrations below 0.1% but above 0.0% are shown as 0.05%.

(c) Elements detected at concentrations between 1.0% and 0.1% are shown as 0.55%.

TABLE 2

Fine Particle Emission Inventory[a]
Los Angeles Area - 1976

STATIONARY SOURCES	Profile	Estimated Fuel Usage (10^9BTU/day) (a)	Emission Factor	Emissions (kg/day)	Mass Fraction < 10 Micron (%)	Fine Particle Emissions (kg/day)
Fuel Combustion						
Electric Utilities						
Natural Gas	27	227.45	1.081 kg/10^9BTU (b)	246.	95.0	233.6
Residual Oil (0.50%)	64	993.42	21.619 kg/10^9BTU (c)	21477.	97.0	20832.4
Landfill & Digester Gas	27	0.82	1.081 kg/10^9BTU (d)	1.	95.0	0.8
Refinery Fuel						
Natural Gas	27	93.03	9.080 kg/10^9BTU (e)	845.	95.0	802.5
Refinery Gas	27	395.95	9.080 kg/10^9BTU (e)	3595.	95.0	3415.5
Residual Oil	1	32.97	21.619 kg/10^9BTU (c)	713.	87.0	620.1
Non-Refinery Industrial Fuel						
Natural Gas	27	421.64	7.567 kg/10^9BTU (f)	3191.	95.0	3031.0
LPG	27	2.74	7.567 kg/10^9BTU (f)	21.	95.0	19.7
Residual Oil	1	53.42	21.619 kg/10^9BTU (f)	1155.	87.0	1004.8
Distillate Oil	2	42.74	23.520 kg/10^9BTU (g)	1005.	98.0	985.1
Digester Gas (IC Engines)	50	6.30	20.430 kg/10^9BTU (h)	129.	99.0	127.4
Coke Oven Gas	27	37.53	7.567 kg/10^9BTU (i)	284.	95.0	269.8
Residential/Commercial						
Natural Gas	51	1181.92	8.071 kg/10^9BTU (j)	9539.	95.0	9062.3
LPG	51	18.08	8.071 kg/10^9BTU (k)	146.	100.0	145.9
Residual Oil	1	22.19	21.619 kg/10^9BTU (l)	480.	100.0	479.7
Distillate Oil	2	22.19	21.619 kg/10^9BTU (m)	480.	98.0	470.1
					SUB TOTAL	41500.8
MOBILE SOURCES						
Highway Vehicles						
Catalyst Autos & Lt. Trucks	53	368.78	2.137 kg/10^9BTU (b)	788.	100.0	788.1
Non-Catalyst Autos & Lt. Trucks	54	1255.16	37.814 kg/10^9BTU (c)	47463.	60.0	28477.6
Medium & Heavy Gasoline Vehicles	54	228.17	43.596 kg/10^9BTU (d)	9947.	60.0	5968.4
Diesel Vehicles	52	125.52	64.200 kg/10^9BTU (e)	8058.	96.0	7736.0
Civil Aviation						
Jet Aircraft	55	44.56	U.S. EPA (1976) (f)	733.	100.0	733.0
Aviation Gasoline	54	1.29	9.08 g/LTO cycle (g)	28.	60.0	16.8
Commercial Shipping						
Residual Oil-Fired Ships Boilers	1	29.41	85.386 kg/10^9BTU (h)	2511.	87.0	2184.7
Diesel Ships	52	17.43	49.102 kg/10^9BTU (i)	856.	96.0	821.6
Railroad						
Diesel Oil	52	19.94	81.837 kg/10^9BTU (j)	1632.	96.0	1566.6
Military						
Gasoline	54	6.03	43.596 kg/10^9BTU (k)	263.	60.0	157.7
Diesel Oil	52	17.81	78.564 kg/10^9BTU (l)	1399.	96.0	1343.3
Jet Fuel	55	16.71	U.S. EPA (1976) (m)	659.	100.0	659.0
Residual Oil (Bunker Fuel)	1	0.27	83.386 kg/10^9BTU (n)	23.	87.0	19.6
Miscellaneous						
Off-Highway Vehicles	52	39.73	78.564 kg/10^9BTU (l)	3121.	96.0	2996.5
					SUB TOTAL	53468.9

(a) From Cass and McRae (1983)

Fine Particle Emission Inventory
Los Angeles Area - 1976

STATIONARY SOURCES	Profile	Emissions (kg/day)	Mass Fraction < 10 Micron (%)	Fine Particle Emissions (kg/day)
Industrial Process Point Sources				
Petroleum Industry				
Refining	28	1943.	61.0	1185.2
Paving and Roofing Materials	19	527.	98.0	516.5
Other (calcining-mineral)	28	454.	61.0	276.9
Organic Solvent Use				
Surface Coating	22	772.	96.0	741.1
Printing	56	9.	99.0	8.9
Storage Loss	56	9.	99.0	8.9
Other	56	12.	99.0	11.9
Chemical Plants	24	1952.	96.0	1873.9
Metallurgical Industry				
Metals-General	65	1716.	100.0	1716.0
Primary Metals	65	4041.	100.0	4041.0
Secondary metals				
Non-Ferrous Metals	69	953.	95.0	905.3
Other	70	799.	95.0	759.0
Metal fabrication				
Non-Ferrous Metals	69	1153.	95.0	1095.3
Other	67	409.	100.0	409.0
Mineral Industry				
Glass Furnaces	17	708.	98.0	693.8
Rock, Stone, Other	33	10433.	10.0	1043.3
Waste Burning at Point Sources	5	209.	100.0	209.0
Wood and Paper Burning	5	263.	100.0	263.0
Food and Agriculture				
Food and Kindred	56	6637.	100.0	6637.0
Grain Mill and Bakery	29	944.	29.0	273.8
Vegetable Oil	56	236.	100.0	236.0
Other	29	427.	29.0	123.8
Miscellaneous Industrial				
Iron and Steel Foundry	70	272.	100.0	272.0
Non-Ferrous Metals	69	182.	95.0	172.9
Other	67	663.	100.0	663.0
Unspecified	67	3514.	100.0	3514.0
			SUB TOTAL	27650.7

FUGITIVE SOURCES	Profile	Fine Particle Emissions (kg/day)
Road and Building Construction	57	176625.0
Agricultural Tilling	57	23633.0
Refuse Disposal Sites	57	746.0
Livestock Feedlots	59	3234.0
Unpaved Road Travel	57	57216.0
Paved Road Travel	58	165400.0
Forest Fires (Seasonal)	60	5790.0
Structural Fires	35	398.4
Fireplaces	63	1244.0
Cigarettes	39	1990.0
Agricultural Burning	61	1244.0
Tire Attrition	38	2409.2
Brake Lining Attrition	41	7712.0
Sea Salt	62	49753.0
	SUB TOTAL	497394.6

TABLE 3

Summary of Particulate Emissions Ranked by Emission Rate

Los Angeles Area - 1976

(Aerodynamic Diameter d_p < 10 μm)

Species	Symbol	Fine Particulate Emissions (kg/day)	Ratio of Element Emissions to Lead
Silicon	Si	89129.1	10.163
Total Carbon	TC	89069.8	10.156
Aluminum	Al	35497.0	4.048
Chlorine	Cl	32469.4	3.702
Sulfates	$SO_4^=$	24711.1	2.818
Sodium	Na	23630.4	2.695
Iron	Fe	21149.5	2.412
Calcium	Ca	10490.0	1.196
Lead	Pb	8769.9	1.0
Magnesium	Mg	8519.2	0.971
Potassium	K	6791.2	0.774
Bromine	Br	3067.1	0.350
Titanium	Ti	2205.4	0.251
Nitrates	NO_3^-	2197.0	0.251
Zinc	Zn	693.3	0.079
Manganese	Mn	594.2	0.068
Nickel	Ni	572.7	0.065
Chromium	Cr	295.5	0.034
Copper	Cu	248.2	0.028
Barium	Ba	193.0	0.022
Vanadium	V	160.2	0.018
Selenium	Se	148.5	0.017
Cobalt	Co	118.6	0.013
Cesium	Cs	102.3	0.012
Arsenic	As	34.9	0.004
Cadmium	Cd	24.9	0.003
Molybdenum	Mo	20.7	0.002
Lanthanum	La	16.2	0.001
Strontium	Sr	12.7	0.001
Neodymium	Nd	10.1	0.001
Praeseodymium	Pr	10.1	0.001
Zirconium	Zr	9.1	0.001
Rubidium	Rb	7.9	0.001
Tin	Sn	6.9	0.0008
Silver	Ag	3.6	0.0004
Antimony	Sb	3.4	0.0004
Bismuth	Bi	0.1	0.0000
Elements Listed		360983. (58%)	
Other Emissions		259032. (42%)	
TOTAL EMISSIONS		620015. (100%)	

TABLE 4

Emissions of Selected Trace Metals
Los Angeles Area - 1976
(Aerodynamic Diameter d_p < 10 μm)

Elemental Emissions From Combustion Sources

STATIONARY SOURCES	Profile	Emissions (kg/day)	Elements Al	Cd	Cr	Fe	Pb	Ni	V	Zn
Fuel Combustion										
Electric Utilities										
Natural Gas	27	233.58	0.0	0.1	1.3	1.3	0.1	1.3	0.0	1.3
Residual Oil (0.50%)	64	20832.44	0.0	4.6	27.1	235.4	13.3	441.6	70.8	20.8
Landfill & Digester Gas	27	0.84	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Refinery Fuel										
Natural Gas	27	802.48	0.0	0.4	4.4	4.4	0.4	4.4	0.0	4.4
Refinery Gas	27	3415.46	0.0	1.7	18.8	18.8	1.7	18.8	0.0	18.8
Residual Oil	1	620.12	0.0	0.0	3.4	19.6	0.0	3.4	3.4	0.0
Non-Refinery Industrial Fuel										
Natural Gas	27	3031.02	0.0	1.5	16.7	16.7	1.5	16.7	0.0	16.7
LPG	27	19.70	0.0	0.0	0.1	0.1	0.0	0.1	0.0	0.1
Residual Oil	1	1004.75	0.0	0.0	5.5	31.8	0.0	5.5	5.5	0.0
Distillate Oil	2	985.14	0.0	0.5	5.3	0.0	5.4	0.5	0.0	5.4
Digester Gas (IC Engines)	50	127.42	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Coke Oven Gas	27	269.79	0.0	0.1	1.5	1.5	0.1	1.5	0.0	1.5
Residential/Commercial										
Natural Gas	51	9062.31	0.0	4.5	49.8	49.8	4.5	0.0	0.0	49.8
LPG	51	145.92	0.0	0.1	0.8	0.8	0.1	0.0	0.0	0.8
Residual Oil	1	479.73	0.0	0.0	2.6	15.2	0.0	2.6	2.6	0.0
Distillate Oil	2	470.13	0.0	0.2	2.5	0.0	2.6	0.2	0.0	2.6
SUB TOTALS		41500.8	0.0	13.8	139.9	395.5	29.8	496.8	82.4	122.2

MOBILE SOURCES	Profile	Emissions (kg/day)	Elements Al	Cd	Cr	Fe	Pb	Ni	V	Zn
Highway Vehicles										
Catalyst Autos & Lt. Trucks	53	788.08	0.9	0.0	0.0	0.9	0.0	0.1	0.0	0.6
Non-Catalyst Autos & Lt. Trucks	54	28477.57	12.2	0.0	0.0	71.2	6008.8	0.0	0.0	6.0
Medium & Heavy Gasoline Vehicles	54	5968.38	2.6	0.0	0.0	14.9	1259.3	0.0	0.0	1.3
Diesel Vehicles	52	7736.05	26.3	0.0	0.0	102.1	7.3	0.0	0.8	17.8
Civil Aviation										
Jet Aircraft	55	733.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation Gasoline	54	16.80	0.0	0.0	0.0	0.0	3.5	0.0	0.0	0.0
Commercial Shipping										
Residual Oil-Fired Ships Boilers	1	2184.75	0.0	0.0	12.0	69.2	0.0	12.0	12.0	0.0
Diesel Ships	52	821.61	2.8	0.0	0.0	10.8	0.8	0.0	0.1	1.9
Railroad										
Diesel Oil	52	1566.56	5.3	0.0	0.0	20.7	1.5	0.0	0.2	3.6
Military										
Gasoline	54	157.73	0.1	0.0	0.0	0.4	33.3	0.0	0.0	0.0
Diesel Oil	52	1343.26	4.6	0.0	0.0	17.7	1.3	0.0	0.1	3.1
Jet Fuel	55	659.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Residual Oil (Bunker Fuel)	1	19.59	0.0	0.0	0.1	0.6	0.0	0.1	0.1	0.0
Miscellaneous										
Off-Highway Vehicles	52	2996.49	10.2	0.0	0.0	39.6	2.8	0.0	0.3	6.9
SUB TOTALS		53468.9	65.0	0.0	12.1	348.2	7318.7	12.2	13.6	41.2

TABLE 4 (continued)

Emissions of Selected Trace Metals
Los Angeles Area - 1976
(Aerodynamic Diameter d_p < 10 μm)

Elemental Emissions From Industrial and Fugitive Sources

STATIONARY SOURCES	Profile	Emissions (kg/day)	Elements Al	Cd	Cr	Fe	Pb	Ni	V	Zn
Industrial Process Point Sources										
Petroleum Industry										
Refining	28	1185.23	0.0	0.0	0.0	11.5	0.6	0.6	0.0	0.0
Paving and Roofing Materials	19	516.46	0.0	0.3	0.0	10.3	0.3	2.8	0.0	2.8
Other (calcining-mineral)	28	276.94	0.0	0.0	0.0	2.7	0.1	0.1	0.0	0.0
Organic Solvent Use										
Surface Coating	22	741.12	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0
Printing	56	8.91	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Storage Loss	56	8.91	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	56	11.88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chemical Plants	24	1873.92	0.0	0.9	0.0	1.1	0.0	0.9	0.0	0.9
Metallurgical Industry										
Metals-General	65	1716.00	0.0	2.1	20.0	100.7	38.9	2.9	2.9	1.8
Primary Metals	65	4041.00	0.0	4.8	47.0	237.1	91.6	6.9	6.9	4.2
Secondary metals										
Non-Ferrous Metals	69	905.35	0.0	0.0	0.5	34.8	113.2	5.0	0.0	95.1
Other	70	759.05	7.3	0.7	0.2	51.2	129.0	0.2	0.0	49.3
Metal fabrication										
Non-Ferrous Metals	69	1095.35	0.0	0.0	0.5	42.1	136.9	6.0	0.0	115.0
Other	67	409.00	0.0	0.1	0.4	3.2	0.8	0.3	0.1	0.2
Mineral Industry										
Glass Furnaces	17	693.84	0.0	0.0	3.8	3.8	3.8	0.3	0.0	0.0
Rock, Stone, Other	33	1043.30	0.0	0.0	0.0	5.7	0.0	0.5	0.0	0.0
Waste Burning at Point Sources	5	209.00	0.0	0.1	0.1	2.4	0.1	1.1	0.0	0.9
Wood and Paper Burning	5	263.00	0.0	0.1	0.1	3.0	0.1	1.4	0.0	1.1
Food and Agriculture										
Food and Kindred	56	6637.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Grain Mill and Bakery	29	273.76	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Vegetable Oil	56	236.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other	29	123.83	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Miscellaneous Industrial										
Iron and Steel Foundry	70	272.00	2.6	0.3	0.1	18.4	46.2	0.1	0.0	17.7
Non-Ferrous Metals	69	172.90	0.0	0.0	0.1	6.6	21.6	1.0	0.0	18.2
Other	67	663.00	0.0	0.1	0.7	5.2	1.3	0.5	0.1	0.3
Unspecified	67	3514.00	0.0	0.6	3.6	27.7	7.0	2.6	0.5	1.8
	SUB TOTALS	27650.7	9.9	10.1	77.1	571.8	591.6	33.4	10.5	309.3

FUGITIVE SOURCES	Profile	Emissions (kg/day)	Elements Al	Cd	Cr	Fe	Pb	Ni	V	Zn
Road and Building Construction	57	176625.00	14483.3	0.0	0.0	5652.0	35.3	7.1	10.6	8.8
Agricultural Tilling	57	23633.00	1937.9	0.0	0.0	756.3	4.7	0.9	1.4	1.2
Refuse Disposal Sites	57	746.00	61.2	0.0	0.0	23.9	0.1	0.0	0.0	0.0
Livestock Feedlots	59	3234.00	265.2	0.0	0.0	103.5	0.6	0.1	0.2	0.2
Unpaved Road Travel	57	57216.00	4691.7	0.0	0.0	1830.9	11.4	2.3	3.4	2.9
Paved Road Travel	58	165400.00	13893.6	0.0	66.2	11445.7	777.4	19.8	38.0	181.9
Forest Fires (Seasonal)	60	5790.00	83.4	0.0	0.0	11.0	0.0	0.0	0.0	0.0
Structural Fires	35	398.40	0.0	0.0	0.0	10.2	0.0	0.0	0.0	0.0
Fireplaces	63	1244.00	0.3	0.0	0.0	0.0	0.1	0.0	0.0	1.5
Cigarettes	39	1990.00	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Agricultural Burning	61	1244.00	5.6	0.0	0.1	0.7	0.0	0.0	0.0	0.0
Tire Attrition	38	2409.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.1
Brake Lining Attrition	41	7712.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sea Salt	62	49753.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SUB TOTALS	497394.6	35422.1	1.0	66.3	19834.1	829.8	30.3	53.7	220.6

TABLE 5

Source Profiles for Fine Aerosol Emissions from Highway Vehicles [a]

	Gasoline Autos and Trucks (Leaded Fuel) (a)	Automobile (Unleaded) (b)	Diesel Engine (c)	Tire Tread (d)	Brake Lining (e)	Highway Composite (f)
1976 Mass Emissions (d_p < 10 micron)						
(Tons/day)	34.75 (60.7%)	0.79 (1.39%)	7.74 (13.6%)	6.04 (10.6%)	7.71 (13.6%)	56.71
Chemical Composition(%)						
Aluminum	0.043	0.12	0.34			0.074
Bromine	8.2		0.031			4.98
Calcium		0.17	0.84		5.5	0.86
Chlorine	5.4		1.69			3.51
Copper	0.004	0.024	0.73			0.10
Iron	0.25	0.11	1.32			0.333
Lead	21.1		0.095			12.8
Magnesium					8.25	1.12
Manganese		0.015	0.027			0.0039
Nickel		0.015				0.0002
Potassium		0.044				0.001
Silicon	0.075	0.51	0.17		15.4	2.17
Sodium			0.37			0.05
Vanadium			0.01			0.00136
Zinc	0.021	0.08	0.23	1.0		0.151
Sulfates	0.213	50.0	4.2			1.40
Nitrates			0.72			0.1
Carbon	54.5	39.0	70.0	87.0	28.3	56.2

(a) From Cass and McRae (1983)

TABLE 6

The Chemical Composition of Selected Sources of Atmospheric Fine Particulate Matter[g]

Chemical Component (a)	Percentages (%) Soil Dust (b)	Road Dust (c)	Fuel Oil Fly Ash (d)	Highway Aerosol (e)	Ammonium Sulfate	Ammonium Nitrate
$SO_4^=$		0.62	31.9	1.40	72.7	
NO_3^-		0.42	4.50	0.1		77.5
Fe	3.2	6.92	1.13	0.333		
Mn	0.11	0.137	0.052	0.0039		
Ni	0.004	0.012	2.12	0.0002		
Pb	0.02	0.47	0.064	12.8		
Cr		0.04	0.128			
Cu	0.008[f]	0.032	0.042	0.10		
Zn	0.005[f]	0.11	0.101	0.151		
V	0.006	0.023	0.339	0.0014		
Cd			0.022			
Co	0.002		0.047			
Sn						
Ti	0.4	0.67	0.008			

(a) Chemical components listed are those under study in the SCAQMD and NASN ambient air quality data base. For complete source composition profiles, see Appendix B of Cass and McRae (1981).

(b) Resuspended soil dust samples taken in the Los Angeles area (Friedlander, 1973).

(c) Road dust fine particle samples taken in Portland, Oregon (Watson, 1979)

(d) Direct average of elemental percentages obtained by Taback et al. (1979) in South Coast Air Basin utility boiler tests 11, 12, 13, 21, 22, 24, 32, 33 as reported in "Total" columns of Tables 4-26 to 4-33.

(e) Composite of gasoline and diesel powered highway vehicle exhaust, plus tire and brake dust. (See Table 5)

(f) Given as < 0.01 %

(g) From Cass and McRae (1983)